EUV Spectra of Highly Charged Ions in the NIST EBIT

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1. Abstract

Measurements of extreme ultraviolet (EUV) radiation from highly-charged heavy ions were made at the National Institute of Standards and Technology (NIST). The ions were generated and confined in an electron beam ion trap (EBIT) and the spectra were recorded with a flat-field grazing-incidence spectrometer in the wavelength range 3-17 nm.

2. EBIT Spectra of Gadolinium

The EBIT was operated at beam energies that optimized the production of Rb-like (27+) to Cu-like (35+) Gd ions. Strong (N-shell) n=4-n=4 transitions were identified with the collisional-radiative (CR) modeling code NOMAD [1, 2].

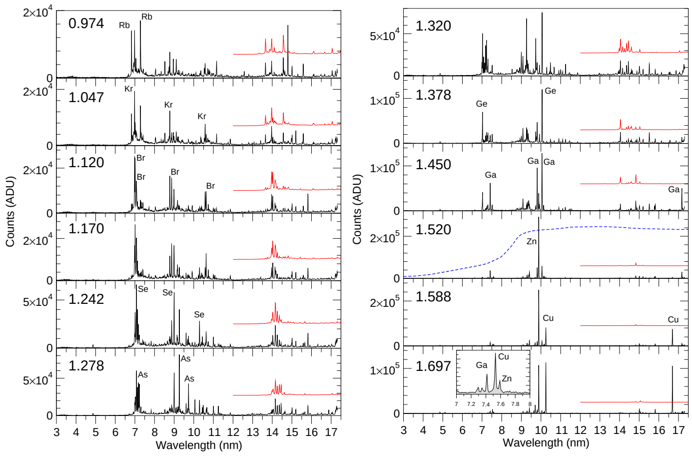

Figure 1: *Experimental spectra of gadolinium ions. Nominal electron beam energies (in keV) are displayed in the upper left corners. Second-order spectra are shifted vertically for clarity. Strong lines are indicated by isoelectronic sequence.*

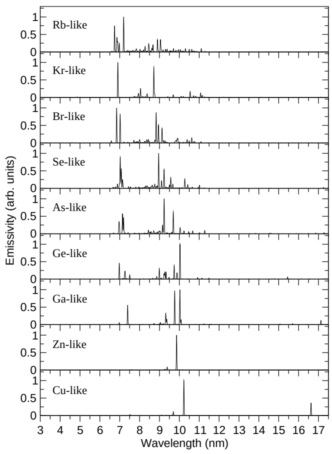

Figure 2: *Synthetic spectra produced with the CR code NOMAD for the n=4-n=4 transitions in gadolinium ions. Charge states are indicated by their isoelectronic sequence.*

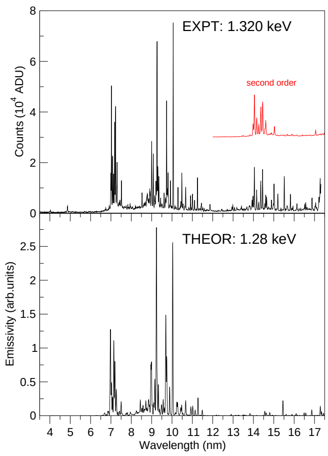

Figure 3: *Comparison of measured spectrum at 1.320 keV and synthetic spectrum at 1.28 keV. Second order spectrum is shifted vertically for clarity.*

3. Gadolinium Data Tables

	Lower level		Upper level		Experiment		Theory	
Ion	Conf.	State	Conf.	State	Current	Previous	Current	Previous
Gd^{33+} [Ga]	$4s^24p$ [1]	$(4p_-)_{1/2}$	$4s4p^2$ [7]	$((4s_+,4p_-)_1,4p_+)_{1/2}$	9.807	$9.811(20)^f$	9.7664	9.655^f
Gd^{34+} [As]	$4s^24p^3$ [1]	$(4p_+)_{3/2}$	$4s4p^4$ [9]	$(4s_+,4p_+^2)_{3/2}$	9.732		9.6954	
Gd^{28+} [Kr]	$4p^6$ [1]	$(4p_+^4)_0$	$4p^54d$ [7]	$(4p_+^3,4d_+)_2$	9.726		9.6932	
Gd^{35+} [Cu]	$4p$ [3]	$(4p_+)_{3/2}$	$4d$ [5]	$(4d_+)_{5/2}$	9.704	$9.7026(15)^d$, $9.7074(15)^c$	9.6999	9.6962^d, 9.6958^n
Gd^{30+} [Se]	$4s^24p^4$ [1]	$(4p_+^2)_2$	$4p^34d$ [11]	$(4p_+,4d_+)_4$	9.684		9.6719	
Gd^{35+} [Cu]	$4d$ [5]	$(4d_+)_{5/2}$	$4f$ [7]	$(4f_+)_{7/2}$	9.636	$9.6349(15)^d$, $9.6398(15)^c$	9.6598	9.6419^n, 9.6426^d
Gd^{30+} [Se]	$4s^24p^4$ [1]	$(4p_+^2)_2$	$4s4p^5$ [12]	$(4s_+,4p_+^3)_1$	9.609		9.5688	
Gd^{34+} [Zn]	$4s4p$ [5]	$(4s_+,4p_+)_1$	$4s4d$ [14]	$(4s_+,4d_+)_2$	9.409	$9.4085(20)^e$	9.3897	9.3651^e
Gd^{33+} [Ga]	$4s^24p$ [2]	$(4p_+)_{3/2}$	$4s4p^2$ [11]	$(4s_+,4p_+^2)_{3/2}$	9.376		9.3183	
Gd^{32+} [Ge]	$4s4p^3$ [7]	$(4s_+,4p_+)_1$	$4s4p^24d$ [33]	$(4s_+,4d_+)_2$	9.352		9.3317	
Gd^{32+} [Ge]	$4s^24p^2$ [3]	$(4p_-,4p_+)_2$	$4p4d$ [15]	$(4p_-,4d_+)_3$	9.300		9.2711	
Gd^{31+} [As]	$4s^24p^3$ [1]	$(4p_+)_{3/2}$	$4p^24d$ [10]	$(4d_+)_{5/2}$	9.262		9.2345	
Gd^{29+} [Br]	$4p^5$ [1]	$(4p_+^3)_{3/2}$	$4p^44d$ [11]	$(4p_+^2,4d_+)_{1/2}$	9.172		9.1315	
Gd^{30+} [Se]	$4s^24p^4$ [2]	$(4p_+^2)_0$	$4p^34d$ [15]	$(4p_+,4d_+)_1$	9.146		9.1050	
Gd^{27+} [Rb]	$4p^64d$ [1]	$(4d_-)_{3/2}$	$4p^54d^2$ [23]	$((4p_+^3,4d_-)_2,4d_+)_{5/2}$	9.105		9.0503	

4. EBIT spectra of Gd, Dy and W

EUV spectra of the lanthanides are dominated by the presence of narrow unresolved transition arrays (UTAs) [3, 4]. These arise from interactions between $4p^64d^{N-1}4f$ and $4p^54d^{N+1}$ configurations and overlap in adjacent ion stages.

Spectra of Gadolinium, dysprosium and tungsten were recorded at beam energies of 0.609, 0.588 and 0.849 keV respectively. These spectra clearly show that with increasing nuclear charge, Z, the UTAs move to shorter wavelengths.

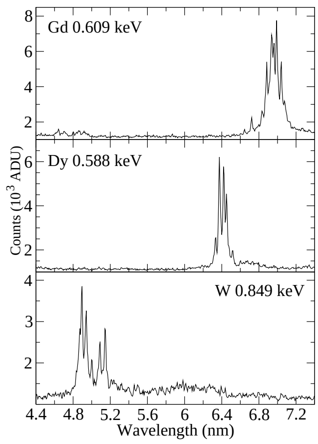

Figure 4: *Experimental spectra of gadolinium at 0.609 keV, dysprosium at 0.588 keV and tungsten at 0.849 keV.*

5. Summary

This work enhances other studies of n=4 to n=4 EUV transitions carried out at NIST on tungsten [5], hafnium, tantalum and gold [6] and can be used for diagnostics of hot plasmas in fusion devices and for studies of trends in atomic structure. The gadolinium data will aid recent research efforts on next-generation lithographic sources at shorter wavelengths [7].

6. References

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